Chandler Wobble

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The Earth rotates about its axis once a day, but does not do so uniformly. Instead, the rate of rotation fluctuates by up to a millisecond per day, and the Earth wobbles as it rotates. Much like the wobble of an unbalanced automobile tire, the Earth wobbles because the mass of the Earth is not balanced about its rotation axis.

The wobbling motion of the Earth was first detected by Seth Carlo Chandler, Jr. in 1891 and has been under observation ever since. In these observations, the wobble manifests itself as an oscillation of the rotation pole about the North Pole of the Earth. This oscillation can be characterized by its period, which is the time that it takes the rotation pole to complete one circuit about the North Pole, and by its amplitude, which is the size of the offset of the rotation pole from the North Pole. Analyses of these observations reveal that the Earth has, in fact, two dominant wobbling motions: (1) an annual wobble with a period of 12 months and an amplitude of about 3 meters, and (2) the Chandler wobble with a period of 14 months and an amplitude that varies between about 3 to 6 meters.

The annual wobble is a forced motion of the Earth that is caused largely by the annual appearance of a high atmospheric pressure system over Siberia every winter. This Siberian high-pressure system annually loads the Siberian crust causing the Earth to wobble with an annual period. The Chandler wobble on the other hand is not a forced motion of the Earth, but is rather a resonant motion that was first predicted by the Swiss mathematician Leonhard Euler in 1765. Euler studied the general translational and rotational motion of rigid bodies and, by applying his theory to the Earth, predicted that if the Earth's mass were not balanced about its rotation axis then the Earth should wobble as it rotates. Assuming that the solid Earth is rigid, the period of this Eulerian wobble is about 10 months.

Despite numerous subsequent attempts by astronomers to detect this predicted wobbling motion of the Earth, it was not until 1891 that Chandler finally detected such a motion, but with a period of 14 months. A year later Simon Newcomb explained the lengthening of the period from 10 to 14 months by the fact that the solid Earth is not perfectly rigid and will therefore deform as it wobbles, and by the fact that the oceans will respond to the wobbling of the underlying solid Earth. Further analysis of the observations by Chandler revealed the additional presence of a wobble with a period of 12 months. The 14-month wobble is now known as the Chandler wobble in honor of the person who first detected the wobbling motion of the Earth.

Frictional forces associated with the wobble-induced deformation of the solid Earth would cause the Chandler wobble to freely decay with an exponential time constant of about 68 years if no mechanism or mechanisms were acting to excite it. Observations of the Chandler wobble taken during the past century show that there are times when the amplitude of the Chandler wobble has actually increased. Thus, some mechanism or mechanisms must clearly be acting to excite the Chandler wobble. Since it is known that the annual wobble is largely caused by changes in atmospheric pressure over land, and since the period of the Chandler wobble is close to that of the annual wobble, many studies have been conducted to determine if atmospheric pressure fluctuations over land are also energetic enough to excite the Chandler wobble. However, these studies have generally concluded that atmospheric pressure changes over land only have about a quarter of the power needed to excite the Chandler wobble. It has only been recently, more than a century after its discovery, that it has been shown that the combination of atmospheric and ocean-bottom pressure changes are likely to have enough power to excite the Chandler wobble.

The recent availability of numerical general circulation models of the oceans has allowed the impact of oceanic processes on the Earth's rotation to be studied. In particular, such models have been used to show that the change in the load on the oceanic crust due to changes in the weight of the overlying column of water associated with changes in the distribution of the oceanic mass is about twice as effective in exciting the Chandler wobble as is the changing atmospheric pressure over land. In fact, the sum of the changing atmospheric pressure over land and the changing ocean-bottom pressure can fully explain the excitation of the Chandler wobble.

Atmospheric pressure changes are the primary cause of the annual wobble, and the sum of atmospheric and ocean-bottom pressure changes are the primary excitation source of the Chandler wobble. Thus, pressure changes associated with weather systems cause the Earth to wobble as it rotates. In addition, the dominant cause of changes in the rotation rate of the Earth, or, equivalently, changes in the length of the day, are changes in the strength and direction of atmospheric winds. In fact, changes in the strength and direction of the jet stream associated with the El Nino / Southern Oscillation phenomenon have been shown to cause changes as large as a half a millisecond in the length of the day. Thus, among its many other consequences, climate change also affects the rotation of the Earth.

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